LARGE–SCALE STRUCTURE AS SEEN FROM QSO ABSORPTION–LINE SYSTEMS

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We study clustering on very large scales — from several tens to hundreds of comoving Mpc — using an extensive catalog of heavy–element QSO absorption–line systems. We find significant evidence that C IV absorbers are clustered on comoving scales of 100 h^{-1} Mpc ($q_0 = 0.5$) and less. The superclustering is present even at high redshift ($z \sim 3$); furthermore, it does not appear that the superclustering scale (comoving) has changed significantly since then. Our estimate of that scale increases to 240 h^{-1} Mpc if $q_0 = 0.1$, which is larger than the largest scales of clustering seen at the present epoch. This may be indicative of a larger value of q_0, and hence Ω_0. We identify 7 high–redshift supercluster candidates, with 2 at redshift $z \sim 2.8$. The evolution of the correlation function on 50 h^{-1} Mpc scales is consistent with that expected in cosmologies with Ω_0 = ranging from 0.1 to 1. Finally, we find no evidence for clustering on scales greater than 100 h^{-1} Mpc ($q_0 = 0.5$) or 240 h^{-1} Mpc ($q_0 = 0.1$).

It has been recognized for some time now that QSO absorption line systems are particularly effective probes of large–scale structure in the universe.[1] This is because the absorbers trace matter lying on the QSO line of sight, which can extend over a sizable redshift interval out to high redshifts. Thus, the absorbers trace both the large–scale structure and its evolution in time, since the clustering pattern can be examined as a function of redshift out to $z \sim 4$. The evolution of large–scale structure is of great interest, since, in the gravitational instability picture, it depends sensitively on Ω_0.[2]

Here we study clustering by computing line–of–sight correlations of C IV absorption line systems, using a new and extensive catalog of absorbers.[3] (A more complete version of this work has appeared elsewhere.[4]) This catalog contains data on all QSO heavy–element absorption lines in the literature. It is an updated version of the York et al. (1991) catalog,[5] but is more than twice the size, with over 2200 absorbers listed over 500 QSOs, and is the largest sample of heavy–element absorbers compiled to date.

Figure 1 shows the C IV line–of–sight correlation function, $\xi_{\rm aa}$, as a function of absorber comoving separation, Δr, for the entire sample of absorbers. The results are shown for both a $q_0 = 0.5$ (*left panel*, 25 h^{-1} Mpc bins) and a $q_0 = 0.1$ (*right panel*, 60 h^{-1} Mpc bins) cosmology.[a] The vertical error bars

[a]Larger bins are required for $q_0 = 0.1$ because, at high redshift, a larger comoving separation Δr arises from a fixed redshift interval Δz.

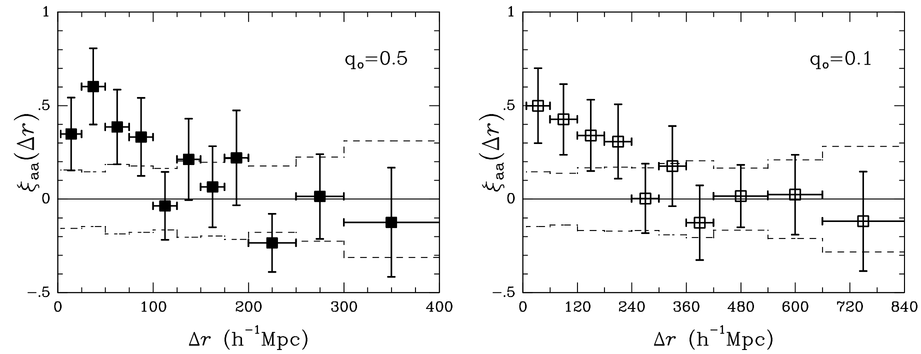

Figure 1: Line–of–sight correlation function of C IV absorbers as a function of absorber comoving separation (from Ref. 4, ©1996 by The American Astronomical Society).

through the data points are $1\,\sigma$ errors in the estimator for $\xi_{\rm aa}$, which differ from the $1\,\sigma$ region of scatter (*dashed line*, calculated by Monte Carlo simulations) around the no–clustering null hypothesis.

Remarkably, there appears to be significant clustering in the first four bins of Figure 1: The positive correlation seen in the first four bins of Figure 1 has a significance of $5.0\,\sigma$. Therefore, there is significant evidence of clustering of matter traced by C IV absorbers on scales up to 100 h^{-1} Mpc ($q_0 = 0.5$) or 240 h^{-1} Mpc ($q_0 = 0.1$). There is no evidence from Figure 1 for clustering on comoving scales greater than these.

We have investigated the evolution of the superclustering by dividing the absorber sample into three approximately equal redshift sub–samples; namely, low ($1.2 < z < 2.0$), medium ($2.0 < z < 2.8$), and high ($2.8 < z < 4.5$) redshift. We find that the significant superclustering seen in Figure 1 is present in all three redshift sub–samples, so that the superclustering is present even at redshift $z \gtrsim 3$. Furthermore, it does not appear that the superclustering scale, in comoving coordinates, has changed significantly since then.

We have examined the clustering signal more closely and find that a large portion comes from 7 QSO lines of sight that have groups of 4 or more C IV absorbers within a 100 h^{-1} Mpc interval ($q_0 = 0.5$). (From Monte Carlo simulations, we expect only 2.7 ± 1.5 QSOs with such groups.) We have found two potential superclusters, at redshift $z \sim 2.8$, among these groups.

The superclustering is indicative of generic large–scale clustering in the universe, out to high redshift $z \gtrsim 3$, on a scale frozen in comoving coordinates that is — if $q_0 = 0.5$ — similar to the size of the voids and walls in galaxy redshift surveys of the local universe.[6−9] It also appears consistent with the

general finding[10,11] that galaxies are clustered in a regular pattern on very large scales, although we have not confirmed that there is quasi–periodic clustering with power peaked at $\sim 128\ h^{-1}$ Mpc.

Our estimate of the superclustering scale increases to 240 h^{-1} Mpc if $q_0 = 0.1$ (see Figure 1), which is larger than the largest scales of clustering known at present. If the structures traced by C IV absorbers are of the same nature as those seen locally in galaxy redshift surveys, the superclustering scale should have a value closer to 100 h^{-1} Mpc . This may be indicative of a larger value of q_0, and hence Ω_0.

We find that the evolution of the correlation function on 50 h^{-1} Mpc scales is consistent with that expected in cosmologies with density parameter ranging from $\Omega_0 = 0.1$ to 1.

Acknowledgments

JMQ is supported by the Compton Fellowship – NASA grant GDP93-08. DEVB was supported in part by the Adler Fellowship at the University of Chicago, and by NASA Space Telescope grant GO-06007.01-94A.

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